MainRoads
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Heavy Vehicle Suspensions - Testing and Analysis:

Phase 3 - eigenfrequency peak loads.

Test Plan

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Executive Summary

“Road-friendly” heavy vehicle (HV) suspensions are critically dependant on correct shock absorber function. In-service testing for “road-friendliness would advantage the transport industry and road asset owners. The former because worn dampers could be replaced before vehicle and payload damage occurs; high-mileage but still serviceable shock absorbers need not be replaced (saving labour and equipment costs). The latter through reductions in road and bridge asset rehabilitation costs through less wear-and tear from HVs with out-of-specification or deficient shock absorbers.

HV tyre wear is used widely as an indicator that suspension dampers are worn. Blanksby *et al*., (2006) showed that this is not a good determinant of damper wear.

Under the joint QUT/MR project *Heavy vehicle suspensions – testing and analysis* it is proposed to develop a low-cost shaker bed made from a modified roller-brake tester to impart a known vibration to the axle. Accordingly, a heavy vehicle brake-test roller machine will be instrumented and modified. It will be used to provide a sinusoidal loading into a HV suspension using eccentricity of the roller/s. This will be attempted for wheel loads varying from tare to full load and for shock absorber conditions from fully-functional to inoperative. Resonant peak force magnitudes should be able to be analysed for axle-hop and body-bounce.

The results from this test programme will:

- be used to determine the threshold beyond which HV suspensions cause tyre wear and road damage compared with when they are new;
- augment the already-underway Main Roads programme being conduced to determine differences due to the “Haire suspension system” (Davis, 2006, 2007; Davis & Kel, 2007; Davis & Queensland Department of Main Roads, 2006a, 2006b) under the test conditions; and
- yield a “proof-of-concept” of moderate-cost testing machine to perform low-cost HV suspension testing.

1. Introduction

The conclusions from DIVINE project (OECD, 1998) were used in Australia to justify the introduction of air-suspended heavy vehicles (HVs) carrying more mass. DIVINE (OECD, 1998), amongst others (de Pont, Thakur, & Costache, 1995; Woodroofe, 1996), noted the results of suspension testing using a shaker bed imparting sinusoidal inputs to determine suspension characteristics.

Under the joint QUT/MR project *Heavy vehicle suspensions – testing and analysis* it is proposed to develop a low-cost shaker bed made from a modified roller-brake tester. This by making one of the rollers eccentric. By placing a test HV's wheels on the roller, a known vibration could be imparted to the axle. Measurement of the resonant peaks of the resultant vibration should yield body-to-axle bounce, and, if sufficiently high rotational speeds can be achieved, axle hop frequencies. The magnitude of wheel-forces at resonance could then be analysed. This would yield conclusions regarding:

- the levels of damper maintenance beyond which HV suspensions cause road damage;
- resonant wheel forces at the threshold of tyre wear at which HV shock absorbers are normally replaced; and
- whether the "Haire suspension system" (Davis, 2006, 2007; Davis & Kel, 2007; Davis & Queensland Department of Main Roads, 2006a, 2006b) makes a difference in these circumstances.

1.1. Aims and objectives

This document sets out the requirements and procedures for:

- modification of a roller-brake test unit;
- experimental methodology to determine comparative HV wheel-forces:
    - at the threshold of tyre wear at which HV shock absorbers are normally replaced;
    - with no shock absorbers;
    - with new shock absorbers; and
- further testing of the "Haire suspension system" in addition to that performed to date (Davis, 2006, 2007; Davis & Kel, 2007; Davis & Queensland Department of Main Roads, 2006a, 2006b).

One of the results from this test programme will be used to determine the threshold at which HV shock absorbers should be replaced compared with when they are usually replaced due to tyre wear.

In addition, the use of the modified roller-brake machine will yield:

- a "proof-of-concept" of moderate-cost testing machine to perform low-cost HV suspension testing; and
- conclusions on levels of maintenance beyond which HV suspensions move outside the envelope of "road friendliness".

Accordingly, a heavy vehicle brake-test roller machine will be instrumented and modified. It will be used to provide a sinusoidal loading into a HV suspension using eccentricity of the roller/s. This will be attempted for wheel loads of:

- no load;
- 1/3 load;

- 2/3 load; and
- full load.

These loads will be for 3 shock absorber condition-states:

- no shock absorbers;
- shock absorbers worn to the point where they have been replaced because tyre wear has become apparent; and
- fully-functional shock absorbers (i.e. within specification) for the suspension being measured.

The “Haire suspension system” *vs*. standard longitudinal air lines (Davis, 2006; Davis & Kel, 2007; Davis & Queensland Department of Main Roads, 2006a, 2006b) will be the two test cases for these loads and condition-states making a total of 24 tests to be conducted.

1.2. Rationale

By placing a test HV’s wheels on a roller, a known vibration can be imparted to the axle. Sweatman used a modified drum on a roller-dynamometer to create an input signal to a HV suspension (Sweatman, 1983). This for purposes of cross calibration of instrumentation on that suspension and to characterise the input function. By measuring the resonant peaks of the vibration modes of the axle and the body-bounce, both the magnitude of these forces and their frequencies should be able to be determined. One of the proposed methods Gyenes *et al.*, (1992) summarised for determining axle hop and damped fundamental frequency of body-bounce was by performing a low-amplitude (1mm) sinusoidal sweep excitation (frequency scan). It was postulated that the eigenfrequencies of the sprung (body) and unsprung (axle hop) components could be found by the highest amplitude wheel-forces measured after such a sweep.

Sinusoidal inputs to test HV suspensions using simulators have been well documented (Hoogvelt, van Asseldonk, & Henny, 2004; Woodroofe, 1996). Prem *et al.*, concluded that constant amplitude sinusoidal sweeps and increasing-force frequency sweeps were of use in characterising suspensions for road-friendliness and in-service testing provided the latter was used in conjunction with type-test data (Prem, George, & McLean, 1998). Ahmadian (2003) noted that using this method on complete HVs in a reaction frame allowed the resonant frequencies of individual HV components to be found, particularly suspension components and the beams of the chassis.

The DIVINE (OECD, 1998) project showed the results of ineffective shock absorbers on HV wheel loadings. Woodrooffe (1996) reported on dynamic loading tests where the wheels of a loaded HV were subject to a 1mm sinusoidal sweep frequency input and the test case for dampers in good condition was compared with the case of ineffective shock absorbers.

The methodology set out in this test plan should allow the recording of wheel-force data for varying levels of shock absorber maintenance and differing loads. Analysis of this data should yield conclusions regarding the levels of damper maintenance beyond which HV suspensions move outside the envelope of “road friendliness” and cause road damage.

2. Background

2.1. "Friendliness" of "road-friendly" suspensions

Road authorities and transport regulators are under continuous pressure from the transport industry to allow "freight efficient" vehicles onto the road network. Outputs from the final report of the DIVINE project (OECD, 1998) were used in Australia to support the argument that air-sprung heavy vehicles (HVs) should carry greater mass under the micro-economic reform popular in the 1980s and 1990s in Australia. One of these reforms was the mass limits review (MLR) project as implemented under the 2nd heavy vehicle reform package (National Transport Commission, 2003). It was concluded that HVs operating at higher mass limits (HML) and equipped with "road friendly" suspensions (RFS) would be no more damaging than conventional heavy vehicles (HVs) operating at statutory masses with conventional steel springs (Pearson & Mass Limits Steering Committee, 1996). This resulted in the implementation of higher mass limits (HML) schemes in various guises in all Australian States. HML allows HVs to carry greater mass in return for, amongst other requirements, being equipped with "road friendly" suspensions (RFS). The documents leading to the introduction of HML noted that suspension damper (shock absorber) health was crucial to RFS being no more damaging to pavements at HML loadings than conventional steel-suspended HVs at statutory mass.

If transport operators were maintaining their vehicles to specification and regulation then there would be no need for concern on the part of road authorities and transport regulators. However, recent work in NSW has indicated (Blanksby et al., 2006) that 54% of HVs in a statistically valid survey did not meet at least one of the requirements of VSB 11. The possible scenario of non-standard MCVs with more than statutory mass (at or higher than HML loadings) on axles or axle groups with worn or out-of specification suspension dampers has now become a better than even-money probability. This is of concern to Australian road authorities and transport regulators.

The anecdotal HV transport industry view of worn shock absorbers and the attendant issue of air suspension health is that the resultant tyre wear is detected quickly. This is then rectified to prevent further increased tyre wear and the associated costs of premature tyre replacement. Despite this view, the Marulan survey (Blanksby et al., 2006) showed that more than half the HVs sampled on the Hume Highway did not meet at least one VSB 11 suspension parameter. This was confirmed in part by Sweatman *et al.*, (2000) who found that:

- quantitative evaluation of shock absorbers did not usually take place in most fleets; and
- the trigger for replacement of shock absorbers was visible leakage or lack of heat after a trip.

From this empirical evidence, it may be inferred that the industry indicators of using tyre wear leakage or temperature to detect out-of-specification or deficient shock absorbers is too late in the maintenance cycle to be effective at meeting the Australian requirements for "road-friendly" HV suspensions. Compounding this issue is the fact that there are no recognised low-cost in-service HV suspension tests in Australia. This has been discussed previously (Starrs *et al.,* 2000, Sweatman *et al.*, 2000) without decisive action by regulators until recently. That action is now occurring on this issue is due to agreement between two Australian States and the Commonwealth (Australia Department of Transport and Regional Services, 2005a, 2005b).

Within the framework described above and its indeterminacy with respect to RFS health, regulators and road authorities have not been able to be certain that air-sprung heavy vehicles (HVs) with RFS are having their "road friendliness" maintained as the suspension dampers wear from normal service.

Costanzi & Cebon (2005) modelled a fleet of HVs with 50% ineffective dampers. That report concluded that, at Higher Mass Limits loadings, pavement and surfacing damage would be 20 - 30% greater than for a comparable freight task with a fleet equipped with dampers in good condition. The Costanzi & Cebon study was for HVs on the Newell Highway. The Newell has considerably thicker pavements than those found in Queensland (Queensland Department of Main Roads, 2007b). If the figure of 50% poorly maintained suspensions modelled by Costanzi *et al*., is equated to the actual status found at Marulan then a HV fleet with 100% functional shock absorbers would save Queensland Main Roads' maintenance budget $59M/annum in 2007 dollars (Queensland Department of Main Roads, 2007a); a saving going forward every year. This is essentially "free money" since HV suspensions should be maintained as a matter of course.

The order of magnitude of these savings indicates that the previously estimated benefit to pavement rehabilitation costs of $14M (Starrs Pty Ltd, Ian Wright and Associates, & ARRB Transport Research Ltd, 2000) was low, even allowing for cost escalation and inflation with the effluxion of time.

Further, the consideration of well-maintained dampers does not include the road safety or workplace health and safety aspects of a HV fleet with in excess of 50% sub-optimal shock absorbers.

2.2. Load-sharing in air-suspended HVs

A great effort went into research and testing of HV suspensions in the 1980s and 1990s. Within these programmes, Gillespie *et al.* (1993) noted that static loads were equalised in most HV multi-axle suspension configurations but that load sharing in the dynamic sense varied markedly between different suspension designs.

The research into dynamic forces imparted to road assets by air-sprung HVs has been reassessed. This has shown that the original research in the 1980s and 1990s indicated very clearly that transfer of air within a HV axle group was not a feature of air suspensions (Simmons, 2005). Mr. Simmons tested air suspended HVs with various longitudinal air pipe sizes between 8mm and 12mm outside diameter and co-authored reports in this field (Gyenes & Simmons, 1994; Simmons & Wood, 1990). He noted (2005) "these pipe sizes will not provide dynamic equalisation as there will not be sufficient transfer between displacers [air bags]..."

Karamihas and Gillespie put it more bluntly, p37 (Karamihas & Gillespie, 2004):

"Air spring suspensions do not possess a dynamic load sharing mechanism."

The inability of conventional air suspensions to load share dynamically in "front-to-back" equalisation mode (i.e.; between consecutive axles) and with a time constant necessary for road travel was confirmed by Davis and Sack (2004). As a by-product of other testing, the air pressure in the high-pressure supply to the air springs of a quad-axle semi-trailer was measured as it was driven over a 65mm step-down profile at 5km/h. The equalisation of air pressure during that process is shown in Figure 2.1.

The "base case" for that programme of work was on vehicles with standard longitudinal air lines of 6.5mm inside diameter and 9.5mm outside diameter. Figure 2.1 shows that equalisation during and after the 2nd axle passed over the step took approximately 3s. Given that HV axles travel over the same point on the road surface separated by about 1/20th of a second, 3s is too slow for any sort of effective and pragmatic dynamic load equalisation to occur.

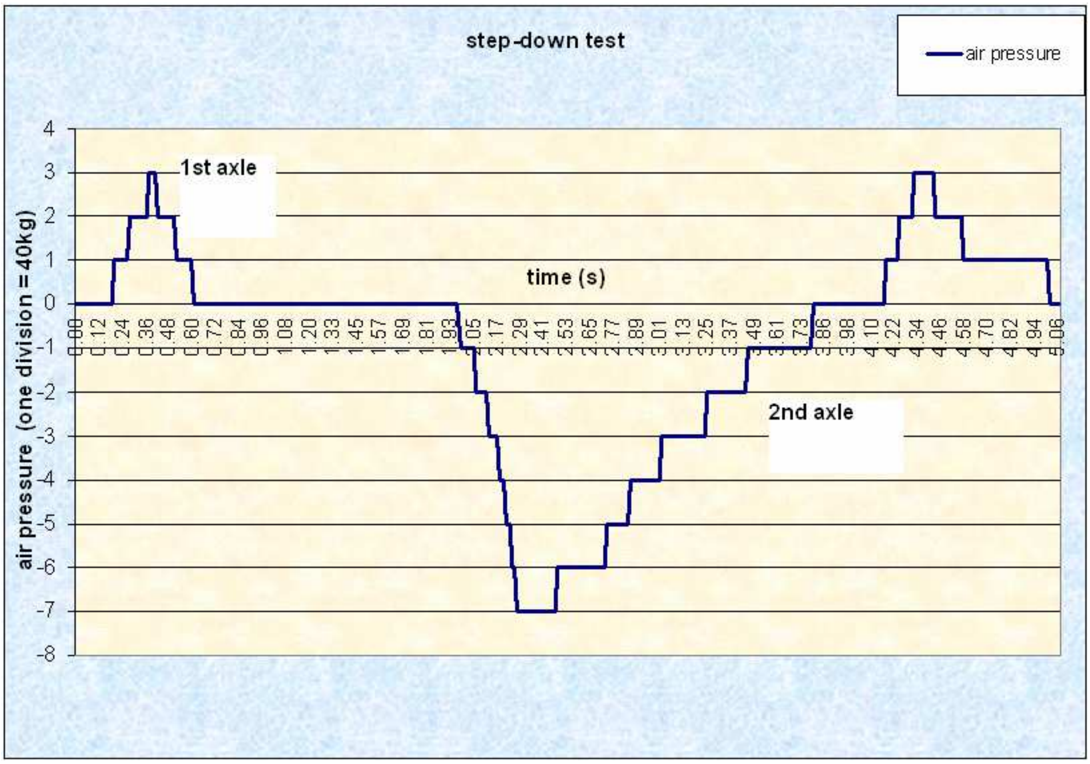

Figure 2.1. Equalisation of air pressure in the air springs of a quad-axle semi-trailer rolling over a 65mm step-down profile.

Referring to the final report of the DIVINE project, p77 (OECD, 1998), authors' italics for emphasis:

"…large dynamic responses and multiple fatigue cycles were observed. These responses were up to *4.5 times the dynamic load allowance* specified in bridge design. Where axle hop was not induced, the dynamic response was much smaller. A probable explanation for this is the fact that the *very limited dynamic load sharing in* *air suspensions* allows the axles in a group to vibrate in phase at axle-hop frequencies. "Crosstalk" between conventional steel leaf suspensions limits this possibility…"

That report was used to justify the introduction of air-sprung HVs at HML loads. It acknowledged that:

- these types of suspensions did not load share in the dynamic sense; and
- the nature of the design of air suspensions created greater dynamic loads than loads induced in conventional steel suspensions under similar circumstances.

Quad-axle semi trailers are being introduced to Australia. If previously the inability of air suspensions to equalise (say) 22.5t loads across tri-axle groups resulted in unequal loadings on one axle over another for that group, the emerging scenario will be 27t similarly imbalanced within a group of 4 axles. Arising from this, road authorities in Australia, officially or otherwise, are becoming increasingly concerned that HVs with air-sprung RFS are not as sympathetic to the network asset as they might otherwise be.

The "Haire suspension system" is a proprietary suspension system that connects HV air springs using larger-than-standard diameter air lines longitudinally as shown in Figure 2, LHS. Note some detail has been removed in Figure 2 for clarity. Larger air lines run longitudinally and connect the air springs fore-and-aft. The transverse air-line remains as standard for this system.

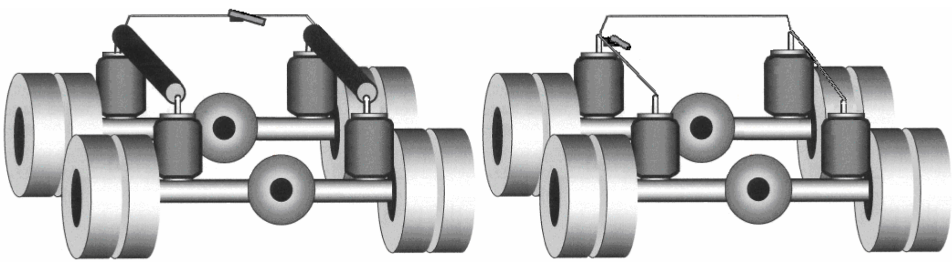

Figure 2. . Schematic layout of suspension with larger longitudinal air lines to be tested (LHS) *vs.* an indicative schematic of suspension with standard air lines (RHS).

Commercial applications of HVs with larger air lines are already being used in HVs on Australian roads. Innovative suspension systems from Kenworth and the "Haire suspension system" utilise larger-than-standard longitudinal air lines. If dynamic load-sharing can be improved for Australian heavy vehicles, the potential for savings on HV suspensions as well as savings on jurisdictional structures, surfacings and pavement maintenance could be considerable. To yield these savings, greater emphasis on, and specification of, the dynamic load sharing ability of air suspensions is required.

2.3. Summary of this section

- Given the 3s time-constant for air transfer (Davis & Sack, 2004), HVs with conventionally-sized air lines are not having their air-spring pressures equalised within similar time-scales as the times between consecutive axle impacts at highway speeds.

- Effective dynamic load equalisation between successive axles within an air-sprung multi-axle group during typical operation does not occur. This phenomenon creates the potential for unnecessarily high pavement and suspension loads, with respect to the other axles in the group, when any given axle encounters a bump.

- With the introduction of quad-axle semi trailers Australia, road authorities are becoming concerned that air-sprung HVs with standard configuration air-lines are not as sympathetic to the network asset as they might otherwise be due to poor dynamic load sharing.

- Alterations to dynamic load-sharing and dynamic wheel loads arising from changing the size of air-spring HV suspension air lines have not yet been investigated adequately.

- Shock absorber wear in HVs is not detected quickly nor in a timely manner (Blanksby et al., 2006). Transport industry indicators of tyre wear, shock absorber leakage or lack of heat arise too late to be effective in keeping a RFS suspension within Australian specification. In-service testing has not been explored in Australia with a definitive way forward.

The testing outlined in the following sections will address parts of these issues by:

- testing a typical HV suspension with shock absorbers at different levels of utility;
- developing a “proof-of-concept” for a moderate-cost high-volume HV suspension testing methodology and associated equipment.
- determining changes in HV wheel force present for different levels of shock absorber functionality; and
- alterations to HV wheel forces with larger longitudinal air lines fitted compared with wheel forces present when standard-sized air lines are fitted.

3. Experimental requirements

The test programme to be undertaken as part of the project *Heavy vehicle suspensions – testing and analysis* and as defined in this document will use an innovative approach to HV suspension testing by the conversion of a roller-brake test bed. This modified machine will be used to provide data from cyclic excitation into a HV suspension.

The following section outlines the equipment and procedural requirements for the test programme. The test cases detailed are:

Condition	**Test cases**							
	Std air lines				**Haire system**			
	Load				**Load**			
	Tare	1/3 load	2/3 load	Full	Tare	1/3 load	2/3 load	Full
No shock absorbers	√	√	√	√	√	√	√	√
Worn shock absorbers (see section 4.1)	√	√	√	√	√	√	√	√
New shock absorbers	√	√	√	√	√	√	√	√

3.1. Equipment

The following equipment and modifications are required to perform the testing:

Item	No.	Source
Crypton roller-brake machine	1	Main Roads. Located at Tramanco P/L, Shoebury St Rocklea
One-tri-axle trailer	1	Haire Truck and Bus
One prime-mover	1	Haire Truck and Bus
Set new shock absorbers to suit trailer	1	Haire Truck and Bus
Set shock absorbers to suit trailer worn to the point where tyre wear is evident	1	Lindsay Bros **or** Haire Truck and Bus
Test masses per Tramanco standard equipment: steel blocks and bins for semi-trailer – load to 20t on the tri-axle group of the trailer (Davis, 2005; Davis & Kel, 2007; Davis, Kel, & Sack, 2007; Davis & Sack, 2006)	8 max	Tramanco P/L to supply
Forklift and driver to move test masses	1	Tramanco P/L to supply
Load cell on outboard bearing of roller. Frequency response: +/- 3dB 0Hz to 100Hz minimum, peak force withstand with 99% linear output: +/- 60kN	1	Tramanco P/L to supply and install
Modifications to roller-brake tester to accommodate load cell and bracing arm.	1	Tramanco P/L to supply and install

Accelerometer		Main Roads. Located at Tramanco P/L, Shoebury St Rocklea
2 channel (minimum) data recording equipment, Tramanco standard equipment (Main Roads previous supply), compatible with load cell and accelerometer, minimum sample rate 100Hz;	1	Main Roads. Located at Tramanco P/L, Shoebury St Rocklea
Ramps (Davis & Kel, 2007; Davis et al., 2007), Figure 3.4	6	Main Roads. Located at Tramanco P/L, Shoebury St Rocklea
Haire suspension system, installed on test vehicle; interchangeable with one standard air line system on test vehicle	1	Haire Truck and Bus
Variable-speed electric motor control centre	1	QUT
or		
Hydraulic motor and controller	1	Haire Truck and Bus

3.2. Roller-brake tester modifications

Roller brake testing machines are generally configured as two or 4 rollers in a rigid frame. The wheels of the vehicle under test are placed between the rollers (Figure 3.3 & Figure 3.4). For normal operation to test the brakes on a vehicle, the vehicle's wheels are spun under the power of the tester. The brakes of the test vehicle are applied. A dynamometer then measures whether the retardation force present from the braking effect of the test vehicle's wheels is adequate.

The brake testing functions of the roller brake tester to hand will not be used for this test programme. The only features of the roller brake tester to be used will be the rollers, the frame, the drive motors and ancillary devices such as the arm on the idler roller. One roller will be modified, Figure 3.3, to provide an eccentric shape as an input to the test HV wheel. The roller coating is approximately 3mm; its removal providing sufficient depth of eccentricity to be similar to that used in previous research (Woodroofe, 1996). The eccentricity will provide an approximately sinusoidal input to the test vehicle's wheel; the tyre-enveloping phenomenon will then smooth out this input, via elasticity of the tyre sidewalls, into a sinusoidal test signal at the axle. This to bring a test HV wheel/s up to resonant speeds for reasons outlined in Section 1.2.

The roller-brake machine will be modified as follows:

- Even up the legs at the bottom of the frame and make them uniform in length by cutting/grinding;

- Weld brace arm as shown in Figure 3.5 (if enough space on the bed for the diagonal brace when the trailer is on it).

- Weld plates on the bottom of the legs to act as pads to bear the loads required during testing. Axle loads will be up to 30kN static, dynamic loads will be determined by testing but may be up to +/- 60kN in addition to the static load (OECD, 1998);

- disconnect the motor drive control centre;

- disconnect all power and control cables from the motor;
- disconnect all control cables from the roller-tester instrumentation;
- disconnect all control cables from the roller-tester control switches (e.g. limit switches);
- reconnect the motor to the QUT-supplied motor drive control centre

  or

- install a hydraulic motor with variable-speed control;
- remove the coating on a roller down to bare metal on two diametrically opposite areas of 900mm width as per diagram, Figure 3.3;
- install an accelerometer (Main Roads previous supply) on the idler roller arm of the modified roller;
- modify outer bearing (i.e. the bearing located on the perimeter frame) of the modified roller to accept a load cell; and
- supply and install a load cell under outer bearing (i.e. the bearing located on the perimeter frame) of the modified roller.

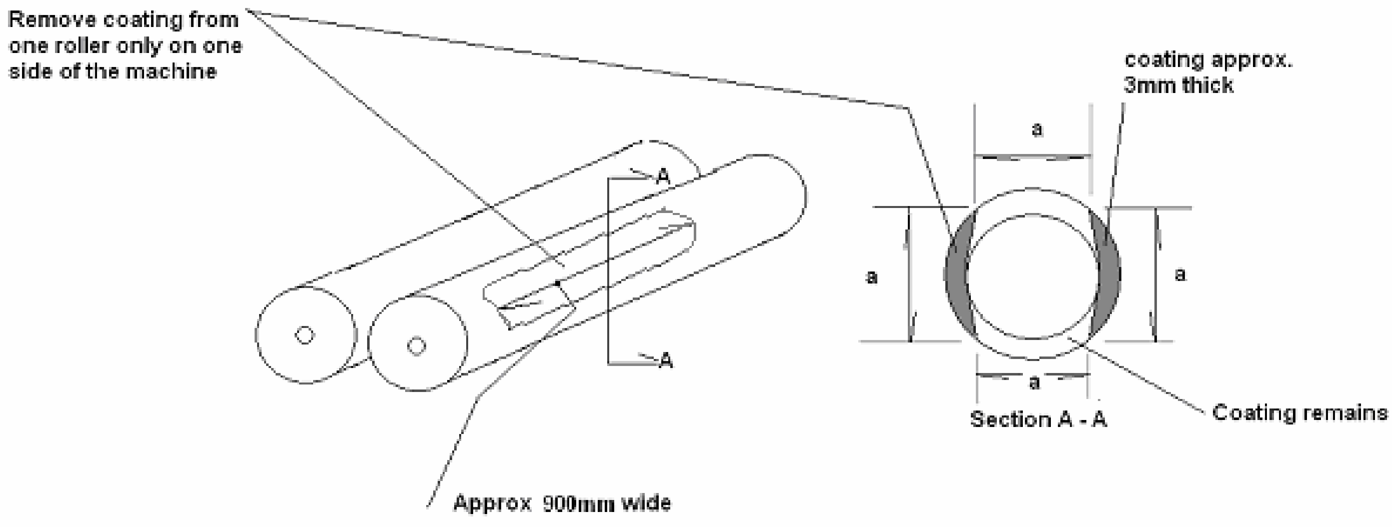

Figure 3.3. Indicative sketch of required modifications to one roller.

3.3. Positioning the trailer on the roller-tester

The ramps used for previous HV testing programmes of the “Haire system” and the low-cost “proof-of-concept” HV suspension testing (Davis, 2007; Davis & Kel, 2007; Davis et al., 2007; Davis & Sack, 2006) will be used to allow the trailer to be positioned on the roller-tester as shown in Figure 3.4.

By the use of a combination of chains and the prime-mover of the combination, the trailer will be locked in place on the roller-bed by:

- locking the prime mover and semi-trailer together with the usual application of the turntable locking mechanism to prevent fore-and aft-movement (Figure 3.4);
- applying the parking brakes of prime mover to prevent fore-and aft-movement (Section 4.2.2); and
- applying the chains from the test bed to the trailer to stop sideways movement (Figure 3.5).

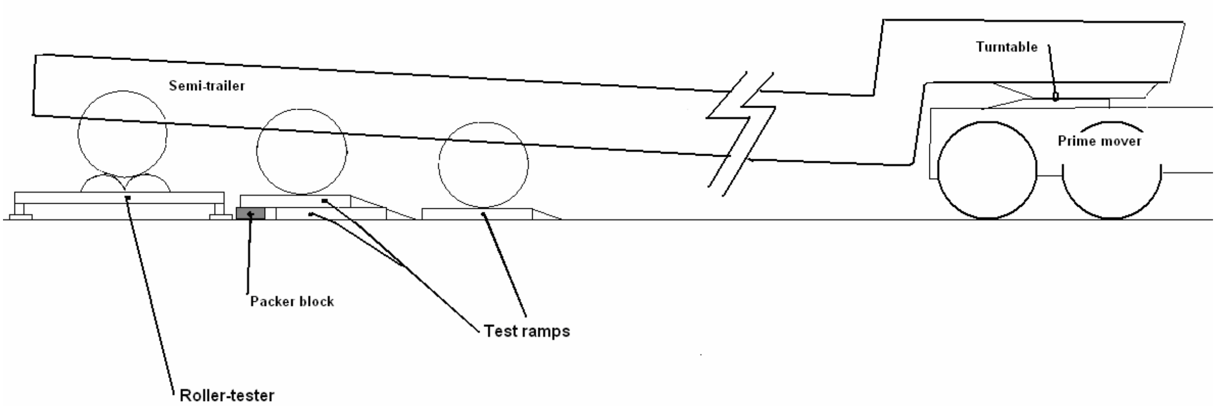

Figure 3.4. Indicative mounting arrangement for the semi-trailer on the roller tester. Side view - not to scale

4. Testing procedure

4.1. General

The following section outlines the methodology and procedures for using a modified roller-brake tester to impart sinusoidal forces to a test HV wheel to measure wheel-forces and tyre-road interface accelerations for 3 condition states:

- no shock absorbers;
- shock absorbers worn to the point where they have been replaced because tyre wear has become apparent; and
- fully-functional shock absorbers (i.e. within specification) for the suspension being measured

at loads of tare, 1/3, 2/3 and full with respect to legal mass on the trailer and for the "Haire suspension system" *vs*. standard longitudinal air lines.

By analysing the data gathered by this process, conclusions should be able to be drawn regarding the levels of damper maintenance beyond which HV suspensions become sub-optimal and cause road damage.

4.2. Detail

The air springs (air bags) need to be configured such that they can be connected using either standard longitudinal air lines or larger-than-industry-standard longitudinal air lines denoted the "Haire suspension system".

The tests will comprise activities outlined in Sections 4.2.1 & 4.2.2.

4.2.1. Preliminary activities, order optional:

- Load the trailer with the nominated test mass(es); and
- Position the trailer's rear wheels on the modified roller-brake tester, Figure 3.4.

4.2.2. Active requirements, order mandatory:

- Secure the semi-trailer/prime-mover combination by engaging the prime-mover's service (wheel) brakes and emergency brake (hand brake);
- Secure the trailer to the frame of the roller-tester as shown in Figure 3.5;
- Connect the air supply to the trailer brake controls such that the brakes are off;
- Start data recording system;
- Run the roller-tester speed from stand-still to maximum (as available from drive-system) increasing the speed by hand control of the variable speed drive (whichever one is available) by approximately 4 Hz / min;
- At body-bounce (~2Hz) and axle-hop resonances (~15Hz) of the rear semi axle, cease ramping speed for 2s;
- After axle-hop resonance peak has been reached and 2s of data at that frequency has been recorded, continue ramping the speed until axle-hop resonance stops;
- Switch off roller-tester at the electrical supply;
- Stop data recording system.

Repeat this process for 4 test mass cases, 2 suspension systems and 3 shock absorber health states.

5. Societal obligations

5.1. Workplace health & safety

Tramanco P/L has a QA system (copy of Certification in Appendix 8) covering WPH&S as well as a WPH&S system (Certificate no. WAA901140955) in place. Within this system, the testing will have the following arrangements to minimise risk to personnel, equipment and plant.

- All electrical work to be carried out by qualified personnel;
- All welding and mechanical work to be carried out by qualified personnel;
- The test vehicle to be secured as shown in Figure 3.5;
- Only personnel required for the testing to be present;
- Drinking water is supplied on site;
- The driver of vehicle/s is to be appropriately licensed; and
- Washroom facilities are supplied on site.
- Appropriate protection in the form of sunscreen, hats, helmets, hearing protection, eyewear, protective clothing to be used as directed or as appropriate to the activity undertaken.

A risk management plan has been lodged with, and approved by, QUT BEE faculty for Stage 2 of the joint QUT/MR project *Heavy vehicle suspensions – testing and analysis.* A complete copy of that document and its approval is available on request; the risk management plan portion of which is contained in Section 5.1.

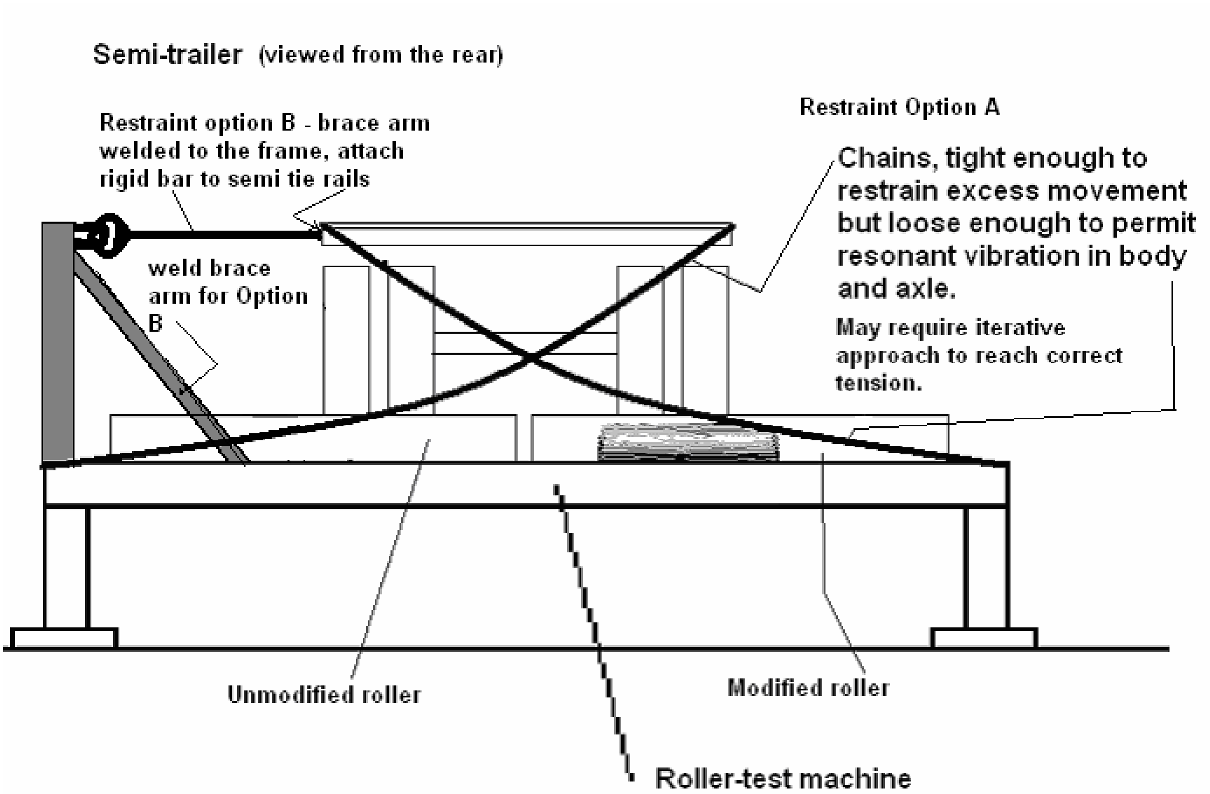

Figure 3.5. Sketch of the securing arrangements for the test vehicle. This view from the rear of the trailer - not to scale.

5.2. Ethics

The testing programme has been submitted to the QUT research ethics office. This resulted in an “exempt” clearance (Lamb, 2007).

6. Conclusion

The generally accepted practice and anecdotal evidence in the road-transport industry is for tyre wear to be used as an indicator that suspension dampers are worn. Blanksby *et al*., (2006) showed that this is not a good determinant of damper wear. The testing as outlined in this test plan will gather data on the resonant wheel-forces present when shock absorbers have worn to the point that tyre wear is evident. This will then be compared with resonant wheel-forces for the case where the shock absorbers are totally inoperable as modelled by removal of the shock absorbers. Resonant wheel-forces for the case where the suspension is new will then allow comparison with the other two cases to determine the threshold at which HV shock absorbers should be replaced.

In addition to these measures, analysis of the data from the testing as outlined herein should inform discussion on:

1. the levels of damper maintenance beyond which HV suspensions move outside the envelope of "road friendliness" and cause road damage; and

2. whether larger longitudinal air lines on air-sprung HVs alter wheel-loads at the occurrence of the highest peak dynamic forces (i.e. at axle and body resonance).

In addition, the use of the modified roller-brake machine will determine whether a "proof-of-concept" for a moderate-cost testing machine to perform low-cost HV suspension testing has been achieved.

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Appendix 1. Risk management plan

RISK MANAGEMENT PLAN

Before Commencement –YOU MUST- refer to the *Risk Management Guide.*

The purpose of '*Risk Management*' is not to make QUT risk adverse but to pro-actively manage risks to ensure the safety, health and wellbeing of all QUT staff, colleagues, students and visitors.

Project Title Heavy vehicle suspension testing and analysis

Project Type (tick appropriate box)							
UG Project	☐	**PG Research Project**	**XX**	**Staff Research Project**	☐	**Commercial**	☐
UG Class Exercise	☐	**PG Class Project**	☐	**Integrated Project**	☐	**Work Activity**	☐
Project Discipline (tick appropriate box)							
Engineering Systems	☐	**Design**	☐	**Urban Development**	☐	**Research**	**XX**
Teaching & Learning	☐	**Faculty Operations**	☐	**External Relations**	☐	**Other (detail below)**	☐
Other..							

Project/Work Details (Specify extent of project)	
The external activities for this research are as follows: A heavy vehicle (HV) test roller machine has been purchased. This will be instrumented and modified to provide an eccentric loading into HV suspension/s. The magnitude and frequency at resonance will be analysed for varying levels of wear on shock absorbers at varying wheel loads. This will yield conclusions on the levels of maintenance beyond which HV suspensions move outside the envelope of “road friendliness” and cause road damage. It is proposed to use a trailer axle on a prime-mover semi-trailer combination for measurements.	
Proposed commencement date	**1/8/7**

All Control Measures MUST comply with State & Federal Legislative Requirements

Project Team Members & Contact phone numbers	**Lloyd Davis, Main Roads 3834 2226** **Roger Sack, Tramanco 0419 337 703** **Tony O'Leary Tramanco 3892 2311**
Project Location (site, room, etc)	**21 Shoebury St, Rocklea.**

RISK CALCULATOR (see guide for explanation on use)					
	CONSEQUENCES				
LIKELIHOOD	INSIGNIFICANT	MINOR	MODERATE	MAJOR	CATASTROPHIC
ALMOST CERTAIN	MODERATE	HIGH	EXTREME	EXTREME	EXTREME
LIKELY	MODERATE	HIGH	HIGH	EXTREME	EXTREME
MODERATE	LOW	MODERATE	HIGH	EXTREME	EXTREME
UNLIKELY	LOW	LOW	MODERATE	HIGH	EXTREME
RARE	LOW	LOW	MODERATE	HIGH	HIGH

RISK ASSESSMENT REGISTER

Complete Table for All identified hazards. Where a 'Documented Control' exists, place the details in the Control Measures column.

Hazard or Task	**Assessed Risks** (List all risks associated with the Hazard or Task)	Appropriate Control Measures	Risk Level Initial / **Final**	**Date Impleme nted**	**Valid Until**	**Individuals Consulted**	**Approver Signature**
Modify roller machine to make rollers eccentric	*Grinding, machining, welding.*	*Workplace Health and Safety measures at Tramanco*	*High* / *low*	*1/9/7*	*1/8/8*	Tony O'Leary Lloyd Davis	
Connect roller machine to power supply	*Electrocution*	*Appropriately qualified trades personnel* *Workplace Health and Safety measures at Tramanco*	*High* / *low*	*1/9/7*	*1/8/8*	Tony O'Leary Lloyd Davis	
Install instrumentation	*Grinding, machining, welding injuries*	*Appropriately qualified trades personnel* *Workplace Health and Safety measures at Tramanco*	*High* / *low*	*1/9/7*	*1/8/8*	Tony O'Leary Lloyd Davis	

Mount loaded heavy vehicle on roller frame	*Crushing injuries if HV not guided properly*	*Appropriately qualified trades personnel* *Workplace Health and Safety measures at Tramanco* *Special ramps as used previously (Davis & Kel, 2007; Davis et al., 2007) to get trailer up on roller-tester.*	*High* / *low*	*1/9/7*	*1/8/8*	Tony O'Leary Lloyd Davis	
Run rollers and take readings from instruments	*HV comes loose, Crushing injuries*	*By the use of a prime-mover semi-trailer combination lock brakes of prime mover. Remove air lines to trailer, thus allowing wheels to run free while trapping the combination on the roller. Chains or solid bar to tie the trailer to the test bed.*	*Extreme* / *moderate*	*1/9/7*	*1/8/8*	Tony O'Leary Lloyd Davis	

Make additional copies of this page as required

APPROVAL			
Conducted By	**Name**	**Signature**	**Date**
Approved By	**Name**	**Signature**	**Date**

Individuals approving this document accept responsibility for the appropriateness of controls and for the validity of the Risk Management Plan.

<u>This document is to be kept by the Approver for the duration of the project, then forwarded to the Faculty Health & Safety Officer</u>

Appendix 2. Logistical sequence for testing – test vehicle preparation

Test vehicle preparation

What	Who	When	Where	Comment
Supply of test vehicle: – tri-axle trailer and prime mover	Bill Haire Haire Truck and Bus (02) 6056 2399 0419 465 714	Before testing commences	Deliver to Tramanco, 21 Shoebury St, Rocklea.	

Appendix 3. Logistical sequence for testing – test vehicle transport

What	Who	When	Where	Comment
Test vehicle transported to Brisbane	As above	Before testing commences.	Tramanco, 21 Shoebury St, Rocklea.	

Any problems, call Lloyd Davis at Main Roads (07) 3834 2226. mobile 0417 620 582

Appendix 4. Logistical sequence for testing – roller tester modifications

Test vehicle preparation

What	Who	When	Where	Comment
Modify roller-tester as per Section 3.2	Roger Sack at Tramanco (07) 3892 2311 0419 337 703	Before testing	Tramanco, 21 Shoebury St, Rocklea.	
Supply variable speed drive and install hydraulic motor	Bill Haire **or** Lloyd Davis	Before testing		**This will depend on availability of variable speed drive from QUT. If not available, Haire Truck and Bus will install hydraulic motor with variable speed control into roller test bed.**

Any problems, call Lloyd Davis at Main Roads (07) 3834 2226. mobile 0417 620 582

Appendix 5. Logistical sequence for testing – performing the tests for the test cases

What	Who	When	Where	Comment
Load test vehicles with test masses (sequentially).	Roger Sack at Tramanco (07) 3892 2311 0419 337 703	Before testing	Tramanco, 21 Shoebury St, Rocklea.	Semi-trailer loaded with bins of scrap steel and solid 1t billets.
Roller test on test vehicle fitted with standard air lines installed.	All.	For first round of testing	Tramanco, 21 Shoebury St, Rocklea.	For 4 test mass states: No load, 1/3 load, 2/3 load and full; and 3 shock absorber health states: none fitted, tyre wear evident and new.
Roller test on test vehicle fitted with Haire suspension system.	Bill Haire Haire Truck and Bus (02) 6056 2399 0419 465 714	For 2nd round of testing	Tramanco, 21 Shoebury St, Rocklea.	For 4 test mass states: No load, 1/3 load, 2/3 load and full; and 3 shock absorber health states: none fitted, tyre wear evident and new.

Any problems, call Lloyd Davis at Main Roads (07) 3834 2226. mobile 0417 620 582

Appendix 6. Responsibilities outside the scope of this test logistics document

Testing and other details which are important but outside the scope of this document.

What	Who	When	Where	Comment
The ongoing cost of the Haire system on a per vehicle basis.	Bill Haire Haire Truck and Bus (02) 6056 2399 0419 465 714			
Impacts on the ADR certification of a vehicle due to the fitment of the Haire system.	Bill Haire.			
Certification of suspension to VSB11 specification (RFS) after the "Haire suspension system" modifications.	Bill Haire.			

Any problems, call Lloyd Davis at Main Roads (07) 3834 2226. mobile 0417 620 582

Appendix 7. Roller bearing load cell specification

"Roger Sack"<roger@tramanco.com.au>
To <lloyd.e.davis@mainroads.qld.gov.au 08/11/2007 01:00PM
cc <TRAMANCORS@Bigpond.com>
Subject: LOAD CELL FREQUENCY

Hello Lloyd,
The response from the manufacturer is detailed below ,,,

"I am not sure of the response of the strain gauges used in the load cells. The PSB 5t is more rigid than the PT5000 or LS and hence would have a faster response. I would expect the response of the load cell to be within miliseconds and have found in the past that the stiffness of the mounting is the parameter that limits the response time. The stiffness of the PSB5t exceeds 153kN/mm and with a deflecting mass of say 2 kg the natural frequency would be about 1.4 kHz."
Please let me know if you need any more information.

Regards, Roger Sack.

Appendix 8. Tramanco QA certification

Quality Endorsed Company

Certificate of Registration

TRAMANCO PTY LTD

ACN 010 101 872

21 Shoebury Street Rocklea QLD 4106 Australia

The above licencee has been assessed and registered by Quality Assurance Services Pty Limited as having the capability to control the quality of goods or services provided in accordance with the conditions of Licence Agreement Number QEC10969 at or from the addresses shown in the Schedule1 to the Licence Agreement, under a quality system complying with the requirements of :

AS/NZS ISO9001:1994
Quality systems-Model for quality assurance in design development production installation and servicing

Certified Date: 6 November 1997
Issue Date: 20 January 1998
Issue No.: 1

Licence No.: QEC10969

Keith Ketheeswaran
Quality Assurance Services, Managing Director

Authorised Local Signatory, QAS

QAS is Accredited by the Joint Accreditation System of Australia and New Zealand, Acc.No 102090QAS

Quality Assurance Services Pty Limited A.C.N. 050 611 642

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